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REPORT

CD NO.

50X1-HUM

COUNTRY IESB

DATE OF _____

INFORMATION 1948

SUBJECT Scientific - Low-temperature research

HOW

DATE DIST. 7 Jul 1949

PUBLISHED Monthly periodical

WHERE

NO. OF PAGES 5

PUBLISHED **Moscow**

DATE _____

PUBLISHED Sep 1948

SUPPLEMENT TO
REPORT NO.

LANGUAGE Russian

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SOURCE

Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki, Vol XVIII, No 9, 1948. (PDB Per Abs 9/49T99 - - Translation requested.)

OBTAINING TEMPERATURES BELOW 1° K BY EXHAUSTING VAPOR OVER LIQUID HELIUM

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Submitted 23 Jan 1948

[Figure referred to is appended.]

1. Introduction

At present great difficulties are encountered in obtaining temperatures below 1° K and in conducting research at such temperatures. Although the Debye and Giauque magneto-caloric method (1926 - 1933) permits obtaining very low temperatures, it has many defects which make it desirable to use the method in which the vapor over liquid helium is exhausted in studies requiring constant temperatures for long periods.

Devices based on this principle have already been described [1 - 6]. The lowest temperature attained by this method up to the present is 0.71°K . (All temperatures in this article are given on the 1939 scale [7], melting point of ice equals 273.16°K .) Such a low temperature can be obtained by reducing the evaporation caused by the creep of the helium II film and by putting in its path a membrane with an aperture 0.05 millimeters in diameter.

A further reduction in aperture diameter would probably lead to still lower temperatures, but as there is normal evaporation in addition to evaporation caused by the creeping of the helium II film, a certain minimum aperture diameter must exist beyond which it is not feasible to go. A diameter of 0.05 millimeters is probably not far from this limit and it must, therefore, be assumed that a temperature below 0.7°K cannot be obtained in an apparatus with a membrane.

- 1 -

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50X1-HUM

However, a new possibility of reducing evaporation caused by the creeping of the film can be explained on the basis of investigations of the properties of the helium II film. It must be remarked that all experiments in studying these properties were conducted under conditions in which the helium II film crept from a lower to a higher temperature. Such conditions are usually brought about automatically in an apparatus, if special measures of some sort are not taken.

Experiments in which the reverse of this phenomenon might be observed are probably not conducted because of certain experimental difficulties. If we assume that temperature differences exert a great influence on the creeping of the helium II film, it would seem reasonable to construct an apparatus in such fashion that the film would move from higher to lower temperatures. (As I have just learned, P. Savich has also followed an analogous train of reasoning.)

Since this could lead to reduced evaporation caused by the helium II film and is of great importance in devising an apparatus in which temperatures below 1°K could be obtained, a series of experiments was undertaken to study this phenomenon.

2. Description of the Apparatus

The apparatus is shown in Figure 1, appended. It is a Dewar glass flask (D_1), 50 millimeters in diameter and 200 millimeters in length, to the inner walls of which a glass membrane is fused. To the membrane is fused a glass capillary abcd, the upper and lower parts of which are 30 millimeters long each. Under the membrane is a tube C, 4 millimeters in diameter and 80 millimeters long, to which a capsule S, 17 millimeters in diameter and 25 millimeters long, is fused.

Ammonium ferric alum is placed in the capsule S to act as a thermometer.

To reduce the heat conduction the inner walls of D_1 are lengthened (F).

A glass tube G, 40 millimeters in diameter, through which helium vapors are exhausted is attached to the Dewar flask. This tube contains two open silver-plated screens R_1 and R_2 to shield the liquid helium from thermal radiation. For the same reason the Dewar D_1 was silver-plated, so that only the lower opening could be seen.

The experiment is conducted in the following manner: after the Dewar flask D_2 is filled with liquid helium the temperature of the liquid helium is then lowered by exhaustion to approximately 2°K and condensation of pure helium begins in D_1 . The condensed helium collected above M makes its way, when the pressure reaches atmospheric pressure, through the capillary abcd. Condensation ends when liquid helium covers half the lower part of the capillary. Then we begin exhausting the vapor over the liquid helium in D_1 with the help of a mercury diffusion pump with a pumping rate 15 liters per sec.

We can assume that with such a set-up a difference in temperature will exist between points b and c and that the helium II film must move from higher to lower temperatures. After the obtained temperature and evaporation rate of liquid helium are measured and these results compared with the results from an apparatus having a membrane with an aperture, it is possible to explain what influence temperature difference exerts on the creeping of the helium II film.

- 2 -

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50X1-HUM

3. Results

The experiments were carried out with three different capillaries, 0.26, 0.53 and 2.03 millimeters in diameter.

The results of preliminary measurements are given in Table I; for the sake of comparison, data obtained with an apparatus having a membrane with an aperture are also shown in Table I.

Experiments carried out with an apparatus with a membrane aperture 2 millimeters in diameter show that temperatures below 1° K cannot be obtained with it. As may be seen from Table I, the same temperature 0.84° K is obtained with a capillary diameter of 2.03 millimeters as with a membrane aperture of 1.0 millimeters. A lower temperature is obtained with a 0.26 millimeter capillary diameter than with a 0.07 millimeter membrane aperture.

Measurement of the evaporation rate shows that the evaporation rate in a capillary apparatus is less than in a membrane apparatus. Thus, for instance with a capillary diameter of 0.26 millimeters the evaporation rate is 0.18 cubic centimeters / hour of liquid helium, which is the same rate for a membrane aperture diameter of 0.07 millimeters.

Table I. Comparison of Measurements

Diameter of membrane aperture in mm	1.0	0.56	0.07
Temperature obtained in $^{\circ}$ K	0.84	0.78	0.73
Diameter of capillary in mm	2.03	0.53	0.26
Temperature obtained in $^{\circ}$ K	0.84	0.75	0.72

The effect can be assumed to be stronger, if the capillary has many curves. Then the helium II film would be enabled to pass several times over a section with the indicated temperature. To prove this assumption an apparatus was constructed having a capillary 1.98 millimeters in diameter and with three curves. In this experiment a temperature of 0.82° K is obtained which is not much less than the temperature 0.84° K obtained with a capillary 2.03 millimeters in diameter and with a single curve.

To enlarge the parts having higher and lower temperatures the capillary is turned in a spiral above and below the membrane. Each spiral comprises three coils, the capillary diameter being 2.0 millimeters. In such an apparatus of capillary diameter 1.90 millimeters a temperature of 0.90° K is obtainable. Of interest is an apparatus having a reduced temperature difference in the capillary section bc.

This is possible through vacuum insulation of the capillary. In such an apparatus, a temperature of 0.80° K is obtained when the capillary diameter is 1.90 millimeters.

Conclusions

1. Apparatus containing a curved capillary makes it possible to obtain a lower temperature than that obtained by apparatus having a membrane with an aperture of the same diameter as the capillary diameter.

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50X1-HUM

2. This may be explained by assuming that there is temperature difference along the capillary above, the higher part of the capillary having a higher temperature than the lower part. Such a temperature distribution reduces the speed of movement of the helium II film and leads to a decrease in the evaporation rate caused by it.

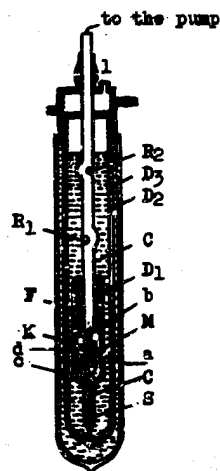
3. Vacuum insulation, triple curvature and the lengthening of the capillary have only a slight effect on the temperature obtained, which fact cannot as yet be explained.

4. A decrease in capillary diameter leads to a drop in temperature. It is possible to assume that greater temperature differences along the capillary increase the effect. Experiments along this line are now being continued.

In conclusion, it is a pleasant duty to express my gratitude to Professor B. G. Lazarev for his interest in our work and his discussion of its results.

The apparatus and its description were made by the master glassblower Ye. V. Petushkov. I take this opportunity of expressing my grateful acknowledgments to him.

[Figure referred to follows.]



- 4 -

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50X1-HUM

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- 5 -

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